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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "Properties of subvisible cirrus clouds formed by homogeneous freezing" *by* B. Kärcher

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p.6, coefficients $a_1, a_3$

I have added a paragraph where I explain how these coefficients are defined and in which manner they are related to the underlying adiabatic process.

p.7, para 3, updraft ceases after freezing event

I agree that the updraft may continue after most of the ice particles have formed. Setting the vertical velocity $w = 0$ is a simplification to compute the growth after freezing is terminated using the equations given in Sect.2.3.

This approximation does not affect the prediction of the ice particle number density. The reason is that the pristine ice particles typically remove supersaturation faster than can be produced by a continuing uplift, and that ice nucleation is terminated as soon as

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the relative humidity falls below the nucleation threshold (which happens very quickly).

Nevertheless, the reviewer is correct. With the assumption $w = 0$ after the freezing event, the ice particle radii $r > \hat{r}$ are underestimated, including the asymptotic radius $r_\infty$. This is because ongoing cooling would produce a residual supersaturation, while constant temperature would rapidly lead to saturation. The residual supersaturation in the case of ongoing cooling is of the order of a few percent and depends only weakly on the vertical velocity (higher $w$ produces more supersaturation but also more particles that more effectively reduce the supersaturation).

It is not easy to give an upper limit of $w$ where this effect is important; in a real cloud, its influence is largely controlled by the time (compared to the growth time) during which $T$ is falling after cloud formation, and this time is clearly variable.

I have performed a couple of numerical simulations to check the effect of ongoing cooling on the mean number radius of ice particles that form at low/high $T$ and with/without ongoing cooling, in the case of $w = 1$ cm/s.

The number of nucleated ice particles shows virtually no dependence on whether cooling continues or not. However, in the analytical approach, the mean ice particle radii are underestimated, because ongoing cooling may deposit a greater mass of $H_2O$ on the ice particles. This effect increases with time. It is more pronounced as $T$ increases (growth rates are faster) and $w$ increases (faster cooling).

It turns out that the effect of ongoing cooling on the mean radius is relatively small at low $T$, and the resulting changes of the sedimentation speed $v_s$ are probably smaller than the uncertainty of $v_s$ itself.

I have explained the above effect in Sect.2.3 and refer to it when introducing Fig.6. Figures illustrating the above statements can be obtained by contacting the Editorial Office (I will provide them, if required.)

p.8, parameter beta and asymptotic radius

The asymptotic radius $r_\infty$ is defined in Eq.(8), just a few lines above where $\beta$ is introduced. It is computed from the overall $H_2O$ mass balance.

p.9, Kent et al. reference

The extinction ratio criterion Eq.20 is explained in Kent et al. (1993) in their Figure 1. It goes back to an earlier work by Kent and McCormick from 1991. Eq.(18) is estimated from their Figure 3e.

For extinction in excess of the limit given by Eq.(19), the SAGEII sensors saturate and clouds are referred to as SAGEII opaque clouds (Wang et al., 1996). I used the limit under the assumption that such opaque clouds do not belong to the SVC category anymore.

It is important to use the 1-micron extinction criteria in conjunction with the extinction ratio threshold, otherwise thick aerosol layers could be counted as aerosol/cloud mixtures.

p.17, scaling laws

The scaling laws for $n$ and $\hat{r}$ have been derived in Kärcher and Lohmann (2002a). This derivation is not repeated here, but I have included this reference for Eqs.(21) and (22).

p.19, and

I have deleted the additional ‘and’.

p.19, Eq.(29)

There is no dependence of $t_s$ on $n$; the value of $n$ is raised to the power of zero. It is just added formally to compare with Eqs. (25)-(28), which do show a dependence on $n$.

p.19/21, sedimentation

This is a good point. In optically thick cirrus, observations reveal a distinct vertical



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cloud structure, with the formation layer (small crystals) at the top, the sedimentation region (large crystals) at the bottom, and a broad transition layer in between. SVCs are optically very thin, but also much thinner in terms of vertical extension than cirrus forming well below the tropopause. As I have cited, thicknesses of SVCs are of the order $500 - 1000$ m.

The few lidar pictures from tropical SVCs show quite little vertical variation, e.g., see Peter et al. (2000) or some of the LITE images by Winker and Trepte (1998). I have previously published a thin (slightly visible) polar cirrus cloud lidar image, showing a more pronounced vertical structure (in the backscatter ratios); however, its thickness of $2$ km may not be representative for most of the SVCs.

In sum, the reviewer may be right, although I think that the effect of a distinct separation between nucleation and sedimentation layer may not be very critical for SVCs. This point adds to the uncertainty introduced using monodisperse spherical particles in calculating sedimentation times. Clearly, I can only give order-of-magnitude estimates with the theoretical tools used in my work. However, the regimes of $w$ and $T$ for which homogeneous SVCs could form are so narrow, that my conclusion about the key role of heterogeneous freezing in SVC formation is still strongly supported by the analysis.

I have added a note in the text discussing Fig.6 addressing this issue.

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Interactive comment on Atmos. Chem. Phys. Discuss., 2, 357, 2002.



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